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Evidence for a Limited-Cascading Account of Written Word Naming

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We address the issue of how information flows within the written word production system by examining written object-naming latencies. We report 4 experiments in which we manipulate variables assumed to have their primary impact at the level of object recognition (e.g., quality of visual presentation of pictured objects), at the level of semantic processing (contextual constraint), and at the level of the lexical retrieval of orthographic word forms (e.g., word frequency). In Experiment 1, pictures were presented either in color or in black and white and had names with either high-to-low or low-to-high frequency trajectories. Both factors had reliable but entirely additive effects on written naming times. In Experiment 2, pictures were presented clearly, in visual noise or blurred, and had names of either high or low word frequency. Again, both factors had reliable but additive effects on written naming latencies. In Experiments 3 and 4, pictures were preceded by a sentence that provided either strong or weak contextual constraint and had names of either high or low word frequency. These 2 variables interacted: The advantage for high-frequency words was observed only with low contextual constraint. We argue that, in combination, these findings support a limited-cascading account of written word production.

Keywords: written naming, cascaded processing, frequency trajectory, word frequency

The question of how information flows within the language processing system has been studied extensively for the production of words in speech. In contrast, there have been only relatively few studies of the temporal dynamics of word production in writing (e.g., Bonin & Fayol, 2000; Delattre, Bonin, & Barry, 2006; Roux & Bonin, 2012; Zhang & Damian, 2010). The relative scarcity of research on written word production is particularly lamentable given both the great importance of orthographic production for literate behavior and the increasing use of the production of text in information technology; for example, in the United Kingdom in 2009 an astonishing 96.8 *billion* text (SMS) messages were sent by mobile telephones (text it, 2012). Further, the study of written word production provides a very useful domain in which researchers can examine the generality of theoretical accounts of word production (in addition to the identification of any possible differences between the two output modes of language expression). Our goal in the present research was to examine information flow in the task of written object naming.

Figure 1 presents a general framework for understanding the major processing levels involved in spoken object naming (e.g., Caramazza, 1997; Humphreys, Riddoch, & Quinlan, 1988; Levelt, Roelofs, & Meyer, 1999) and written word production (e.g., Barry, 1994; Houghton & Zorzi, 2003; Morton, 1980; Rapp & Caramazza, 1997). Many theories of object processing assume that a pictured object, after perceptual analysis, achieves object *recognition* by accessing a "pictogen" (Morton, 1985) or a stored structural description system (e.g., Humphreys et al., 1988; Marr, 1982), which may be seen as a "lexicon of visual object forms" (Coltheart, 2004). This recognition system categorizes perceived objects as being familiar or known. A recognized object will then activate its conceptual and semantic representation, which entails the activation of stored knowledge of the functional, associative and other properties of the object. This functional separation between the object recognition and semantic systems is not always made explicit in models of spoken word production (e.g., Caramazza, 1997, Figure 1), and some models appear to suggest that the functions of object recognition and comprehension are positioned within a common conceptual level. Models of speech production—even those that use object-naming data as supporting evidence—have not always addressed this issue directly, which is understandable given their emphasis on post-conceptual psycholinguistic processes. However, we submit that the distinction between object recognition and semantics is a major one for fully understanding object naming, and it is also central to the rationale of the studies to be reported here. Coltheart (2004) reviewed a body of neuropsychological evidence that supports the functional

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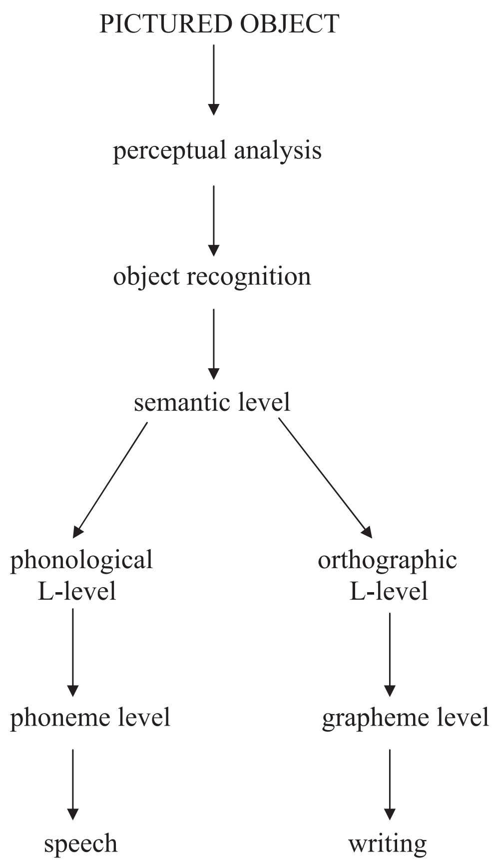

Figure 1. A general model of the processes underlying spoken and written naming.

separation of object recognition and semantics. There are neurological patients with severe semantic-level impairments (e.g., due to semantic dementia) who show no impairments of object recognition as assessed by performance in the object-decision task (e.g., Fery & Morais, 2003; Hovius, Kellenbach, Graham, Hodges, & Patterson, 2003; Sheridan & Humphreys, 1993). Coltheart (2004) argued that dissociations between intact object recognition and impaired semantic access may be "simply explained by models of visual object processing that posit the existence of a pictorial lexicon or pictogen system that is distinct from a semantic system" (p. 1166).

Most theories of object naming also propose that access to the word-form of the name of a presented object necessarily requires semantic mediation (although this does not necessarily mean that *all* stored knowledge must be fully activated; Riddoch & Humphreys, 2001). The existence of a possible "direct" nonsemantic route from object recognition to lexical representations in naming has been debated, but evidence for it has proved to be remarkably elusive (e.g., Brennen, David, Fluchaire, & Pellat, 1996; Kremin, 1986). This is unlike the case of oral reading, where patients with dementia have been reported who can to read aloud words with irregular spelling-to-sound correspondences (such as *leopard*) that they cannot comprehend (e.g., Blazely, Coltheart, & Casey, 2005; Schwartz, Saffran, & Marin, 1980). There exist no unambiguous cases of patients who can name objects they are unable to comprehend. Even in patients with severe semantic impairments (e.g., due to dementia of the Alzheimer type), it has been extremely difficult to contradict the hypothesis that naming was not driven by semantic codes, even when these are very impoverished (e.g., Hodges & Greene, 1998).

We assume that the same semantic level is common to both spoken and written modes of production (Bonin & Fayol, 2000). Information from the semantic level is transmitted to the lexical level, where there is access to and retrieval of stored word-forms. Finally, there are the output levels specific to each mode of expression: a phoneme level for speaking and a grapheme level for writing. The grapheme level primarily specifies abstract letter identities and may also involve simple and complex graphemes (Kandel & Spinelli, 2010), geminates (Caramazza & Miceli, 1990), and vowel-consonant information (Cubelli, 1991). Activation of these sublexical levels, along with more peripheral processes (such as syllable motor programs [Roelof, 1997] and the control of prosody and intonation for speech and allographic selection and graphic motor patterns [Ellis, 1982] for writing), ultimately allows the behavioral execution of words, as articulation in speech and the production of letters in writing. The view that speaking and writing share conceptual and semantic processes but diverge during phonological or orthographic word-form encoding is supported by various lines of evidence (e.g., Bonin & Fayol, 2000; Perret & Laganaro, 2012). Further, as we argue in greater detail in the General Discussion, written naming does not require obligatory mediation of phonological codes (e.g., Rapp, Benzing, & Caramazza, 1997).

For spoken word production, Levelt (1989; Levelt et al., 1999) proposed that semantic information must first pass through an abstract lemma level, which provides information about the syntactic category and grammatical gender, before a word's phonological word-form can be accessed. However, Caramazza (1997) and Caramazza and Miozzo (1997, 1998) have criticized the existence of a separate lemma level and proposed that conceptual/semantic representations map directly onto phonological word-forms. The lemma versus word-form debate has not been fully engaged in the domain of written word production (although Pickering & Branigan, 1998, have entertained the idea that lemmas exist in both written and phonological word production). For the purposes of our present research on written naming, we shall adopt Goldrick and Rapp's (2007) proposed neutral term of "L-level" to refer to holistic lexical representations (or word-forms), and we further distinguish between a phonological L-level and an orthographic L-level. Activation of L-level representations will then pass information to their respective sublexical phoneme and grapheme levels.

It is important to note that the semantic, lexical, and phonological levels posited in Figure 1 for naming are the same as those necessary for word production in spontaneous speech. (They broadly correspond to the major levels of conceptualization, formulation, and execution; Bock & Levelt, 1994.) Indeed, it is exactly this commonality of processing levels in naming and speech that has made the experimentally tractable task of object naming such a popular and useful means of studying these key aspects of language production. A central but still unsettled theoretical question concerns the temporal dynamics of information flow between these levels. In particular, the question is whether they operate *discretely*, where one processing level must be completed before the next can begin, or in some form of *cascade*, where there is a more continuous and temporally overlapping flow of information between levels. It is also possible to distinguish between "full-cascading" and "limited-cascading" accounts of speech production (Kuipers & La Heij, 2009). In full-cascading accounts, the flow of information is not restricted in any way, such that activation at one level will activate *all* subsequent levels (e.g., Dell, 1986); in Figure 1, this would be from object recognition through semantics to the L-level. In such models of naming (e.g., Humphreys et al., 1988), a presented object (e.g., DOG) would activate at the object recognition level many representations of structurally similar things (DOG, CAT, WOLF, HYENA, HORSE, etc.), each of which would then activate its associated semantic representation; some semantic features would be common to different activated objects (e.g., <four-legged animal>), and others would be more specific to particular objects (e.g., <barks>, <can be trained to assist blind people>). Semantic information then cascades to activate the phonological forms of object names ("dog," "cat," and "wolf") in proportion to their degree of semantic match. The important point for the purposes of the present research is that full-cascaded models claim that activation from the object recognition and semantic levels is continuously passed on to the L-level, and so factors that affect ease of processing at preceding levels will cascade to affect naming times. Full-cascading models of speech production posit that a semantically activated concept will activate many L-level representations along with their corresponding sublexical phonology (i.e., that there will be phonological encoding of all activated words).

In contrast, limited-cascading accounts posit restrictions on the extent of information flow. Limited-cascading models of speech production have been proposed by Levelt et al. (1999) and Bloem and LaHeij (2004). The influential Levelt et al. (1999) theory is often presented as a classic serial-discrete model because it is proposes that activation is transmitted from lemmas to word-forms discretely and serially. However, the theory also proposes that conceptual information flows to lemmas in cascade, and so a conceptual representation (e.g., <dog>) will activate more than one lemma (e.g., "dog" and, if to a lesser extent, "cat"). Only once a lemma is selected for production will its word-form be activated; there is no cascading of information from lemmas to the word-forms of nonselected items, and so nonselected words will not be phonologically encoded. In this model, cascading ends at the point of lemma selection, and the lemma to word-form to phoneme transmission process is claimed to operate discretely, in a manner independent of (or "isolated" from) influences from previous levels. The only condition where there may be parallel or cascaded lemma to word-form transmission is for objects with near-synonymous names, such as *sofa–couch*, where both names may be phonologically encoded (Jescheniak, Hahne, & Schriefers, 2003; Peterson & Savoy, 1998). In contrast, Bloem and LaHeij (2004) proposed a more limited-cascading view of speech production whereby a concept selected to be produced in speech will activate a semantic cohort of lexical items, all of which will be phonologically encoded. Thus, on this view, cascaded processing begins at the stage of semantically activated L-level representations.

Although there have been extensive debates concerning how information flows within the language system for spoken word production (e.g., Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Jescheniak & Schriefers, 1997, 1998; Jescheniak, Hahne, & Schriefers, 2003; Levelt et al., 1991; Peterson & Savoy, 1998), an emerging consensus is that there is at least some cascaded processing (Kuipers & La Heij, 2009). Recent studies of spoken naming have begun to address the issues of precisely where, and under which circumstances, restrictions upon cascaded processing operate (e.g., Oppermann, Jescheniak, Schriefers, & Görges, 2010; Roelofs, 2008), and the aim of our present research is to examine similar issues in written word production.

Particularly compelling evidence for the full-cascading account of spoken word production has come from the picture–picture task (Meyer & Damian, 2007; Morsella & Miozzo, 2002; Navarrete & Costa, 2005). In this paradigm, participants are presented with two overlapping pictures, one in green ink and one in red ink, and are told to name the target object in green ink and to ignore the distractor object in red ink. In an influential study of spoken naming, Morsella and Miozzo (2002) found that English naming latencies were facilitated when the name of the distractor was phonologically related to the target (e.g., the target BED was named faster with the distractor BELL compared with HAT). There was no such effect when a separate group of Italian participants, for whom the picture names had no phonological similarity, named the identical stimuli, which reduces the likelihood that any uncontrolled perceptual or conceptual relationship between the objects contributed to the observed phonological facilitation effect. Morsella and Miozzo's (2002) results clearly support a cascade model, as they show that the phonological forms of the (irrelevant) distractor pictures were activated and affected target naming-times. Meyer and Damian (2007), Navarrete and Costa (2005), and Roelofs (2008) have also reported phonological facilitation effects in spoken naming in this paradigm, although Jescheniak et al. (2009) did not replicate the effect. Colomé and Miozzo (2010) have further extended this important result in their study of Spanish–Catalan bilinguals. Participants orally named objects only in Catalan, but Colomé and Miozzo found that distractor pictures whose names in Spanish were phonologically related to the targets also facilitated naming. For example, the object VEST ("armilla" in Catalan) was named faster when accompanied by the distractor object SQUIRREL ("esquirol" in Catalan and "ardilla" in Spanish; i.e., phonologically related to the target) than by a completely unrelated, control object. The fact that the phonological forms of translation equivalents of the names of distractor pictures become activated in bilinguals provides further compelling evidence for a full-cascaded account of spoken naming.

Roux and Bonin (2012) have recently used the picture–picture interference paradigm to investigate the cascading of information during *written* word production. In one experiment, participants wrote the names of target pictures accompanied by superimposed distractor pictures that had phonologically and orthographically related names (e.g., COUTEAU and COURONNE; an English example would be CAMEL and CAMERA) or unrelated names. In a second experiment, the related condition consisted of target and distractor pictures whose names shared an initial letter but not the initial sound (e.g., CANARD and CITRON; an English example would be GATE and GNOME). Written latencies were faster in the related than in the unrelated conditions in all experiments, which suggests that, after object recognition and semantic access, activation cascades to the spelling representations at the orthographic L-level.

Although the findings from the picture–picture task support full-cascading accounts of spoken word production, the paradigm has been criticized on the grounds that the simultaneous presentation of two superimposed pictures complicates visual identification processes (Jescheniak et al., 2009), by posing difficulties of selective attention necessary for recognition, and may artificially lead, at least on some trials, to the selection of *both* the target and distractor objects for word-form encoding (Kuipers & La Heij, 2009). Roelofs (2008) found that the phonological facilitation effect was found for all parts of the distribution of naming times (i.e., the difference between the related and unrelated items was found for both fast and slow naming times), which he argues excludes the possibility that the effect occurred on some of the trials only. However, it is still possible to argue that the picture-picture task might *always* result in the names of both objects being phonologically encoded. Indeed, the presentation of two superimposed but visually complete (and so nonoccluded) pictures might be considered to be rather unnatural and so engages naming processes in a rather artificial or atypical fashion. Given these concerns, it is clearly desirable to use a more natural or straightforward experimental task to see if it may provide converging evidence for cascading processing. This was precisely the goal of our present study that used the simple and direct task of writing the name of a single picture.

In our experiments, we followed the basic logic used by Humphreys et al. (1988) and Griffin and Bock (1998) in their studies of spoken word production. According to full-cascading accounts of word production, the effect of an experimental manipulation or variable that primarily affects one processing level (N) would be passed on to dynamically affect all subsequent levels (N + 1, N + 2). Humphreys et al. (1988) found that the effects of structural similarity and word frequency interacted, such that the expected effect of the word frequency of object names was found only for objects from structurally dissimilar categories (typically, man-made objects). Since structural similarity and word frequency are assumed to act at different and nonadjacent levels of processing (namely, the object recognition level and the L-level, respectively), the observation that the two factors interacted has been taken as support for a full-cascaded model, in which there is continuous transmission of information between processing levels. Similarly, Griffin and Bock (1998) found that the effects of contextual constraint and word frequency interacted. When the selection of a target name was highly predictable (e.g., producing "kite" following a high-constraint, lead-in sentence frame "On windy days the boy went outside to fly his __"), the effect of word frequency was not reliable, whereas objects with high-frequency names were named reliably faster than those with low-frequency names when the target names were not predictable from the sentence context. As contextual constraint has its primary impact at the semantic level, and word frequency is generally assumed to have its primary impact at the L-level, Griffin and Bock's observed interaction between the effects of these variables also supports a cascading account of speech production.

Our studies of written naming follow the same methodological logic to examine whether information flows in a continuous, cascaded or a serial, discrete manner between the object recognition level and the orthographic L-level (studied in Experiments 1 and 2) and between the semantic level and the orthographic L-level (studied in Experiments 3 and 4). Interactions between the effects of the experimental manipulations of how pictured objects are presented (by varying their visual format and what precedes their presentation) and intrinsic characteristics of their names (such as word frequency) would support the view that information flows in a cascaded manner in written naming. In contrast, the theoretical view that information flows in a serial-discrete manner (or that there are restrictions on the flow of information) would predict that these variables would have additive effects.

Experiment 1: Picture Format and Frequency Trajectory

In Experiment 1, we examined the influence of picture format and frequency trajectory on written naming latencies in order to examine whether the two variables have additive or interactive effects. Frequency trajectory refers to the variations in the frequency of words as they are encountered during a lifetime (Zevin & Seidenberg, 2002, 2004). Words with high-to-low frequency trajectories (e.g., *clown, snail*) are those that are more frequent in childhood than in adulthood, whereas words with low-to-high frequency trajectories (e.g., *cigar, bell*) are more frequent in adulthood than in childhood. As such, frequency trajectory has been taken to be an objective measure of age of acquisition, such that words with high-to-low frequency trajectories are early acquired, and words with low-to-high frequency trajectories are late acquired. We reasoned that the experimental manipulation of presentation format, operationalized here as a contrast between colored and black-and-white versions of the same pictures, would have its primary impact at the object recognition level, whereas the variable of frequency trajectory would have its primary impact much latter in the naming process, at the level of accessing or executing orthographic word-forms. If information cascaded from the object recognition level to the orthographic L-level, then the effects of the two variables should interact.

Rossion and Pourtois (2004) created colored versions of the Snodgrass and Vanderwart (1980) drawings. (A professional graphics artist created colored and textured versions using Adobe Photoshop.) Rossion and Pourtois (2004) found a clear advantage of the addition of color to the standard black-and-white Snodgrass and Vanderwart (1980) drawings on spoken naming speed and accuracy. The color advantage was larger for objects with a "diagnostic" color (such as LEMON and TOMATO) and for items from structurally similar categories (such as fruits and vegetables), but importantly, the advantage was also found for both objects without a single diagnostic color and for structurally distinct, man-made objects. Rossion and Pourtois suggested that color facilitates the object recognition stage involved in picture naming because color is an integral part of the structural representation of objects.

Reliable effects of frequency trajectory have been found in both spoken and written naming latencies (Bonin, Barry, Méot, & Chalard, 2004). These effects have been interpreted as being located at or around word-form levels but not at the level of object recognition or comprehension (Bonin, Chalard, Méot, & Barry, 2006; see Johnston & Barry, 2006, for a review).

Method

Participants. A group of 38 psychology undergraduates (mean age = 18 years old) from the University of Bourgogne (in

Dijon, France) took part in the experiment in exchange for course credits. The participants were native speakers of French and reported having normal or corrected-to-normal vision.

Stimuli. Fifty-two black-and-white drawings were selected from Snodgrass and Vanderwart (1980), and the colorized versions of the same pictures were taken from Rossion and Pourtois (2004). Each picture was transformed to fit into an 8-cm square when displayed on the computer screen. The pictures had either a high-to-low (early-acquired) name or a low-to-high (late-acquired) name, and the two sets of 26 items were matched on cumulative word frequency (.80), name agreement (93% and 95%), image agreement (3.63 and 3.75), rated visual complexity (3.20 and 3.09, on a 5-point scale), number of letters in their names (6.04 and 6.27), and the bigram frequencies of their names (log-transformed: 3.01 and 3.02). The names of pictures are presented in Appendix A.

Apparatus. The pictures were presented on a Macintosh (iMac) computer running the Psyscope v.1.2.5 software (Cohen, MacWhinney, Flatt, & Provost, 1993). A graphic tablet (Wacom Intuos 2), with a contact pen (UP-401), was used to record written naming latencies.

Procedure. The participants were randomly assigned to one of two groups, who received either black-and-white or colorized pictures. Participants were tested individually, seated comfortably in a quiet room. There was a familiarization phase, followed by the experiment proper. In a familiarization phase, the whole set of experimental pictures, along with their printed names, was presented for learning, and participants were tested to ensure that they knew the names of the pictures. In the experimental phase, the pictures were presented alone in a different random order, and the participants had to write down their names. Each trial began with a fixation point (+) displayed in the middle of the screen for 500 ms. A picture was then displayed in the middle of the screen and remained there until the participant's response. Participants were instructed to write down the name of the picture as quickly (and as accurately) as possible on the graphic tablet. In order to avoid either large arm movements or premature contacts, participants were instructed to hold the pen directly above the graphic tablet prior to making each handwritten response. Written latencies were measured to the nearest millisecond from the onset of the visual display to the initialization of the first handwriting movement corresponding to the production of the first letter in the object's name. Ten practice trials preceded the presentation of the 52 experimental trials. The intertrial interval was 5 s.

Results

Responses were discarded from the latency analyses whenever any of the following conditions applied: (a) a spelling error was produced; (b) a technical error occurred; (c) the participant could not retrieve the picture name or used a name other than the target; (d) the written latency was longer than 2,000 ms or shorter than 300 ms; or (e) the latency was above two standard deviations from both the participant and item means. The application of these criteria resulted in the exclusion of 7% of the data.

Analyses of variance were performed on written latencies and on errors with the factors picture format (black-and-white vs. colorized drawings) and frequency trajectory (high-to-low vs. low-to-high). Analyses were conducted separately with participants (F_1) and items (F_2) as random factors. In the analysis by participants format was a between-participants factor and frequency trajectory was a within-participant factor. Mean written naming latencies in each condition, together with their standard deviations and error rates, are presented in Table 1.

Written naming latencies were faster (on average by 114 ms) to colorized than black-and-white drawings, $F_1(1, 36) = 11.53$, $MSE = 22{,}718.29$, $p < .01$; $F_2(1, 50) = 87.16$, $MSE = 4{,}154.22$, $p < .001$, and were faster (on average by 22 ms) for objects with high-to-low than with low-to-high frequency trajectory names, $F_1(1, 36) = 5.56$, $MSE = 2{,}043.55$, $p < .05$; $F_2(1, 50) = 4.49$, $MSE = 3{,}292.80$, $p < .05$. Importantly, there was no interaction between the effects of these two variables (Fs < 1).

The analyses of error rates revealed a main effect of frequency trajectory, $F_1(1, 36) = 16.95$, $MSE = .001$, $p < .01$; $F_2(1, 100) = 7.37$, $MSE = .003$, $p < .01$, with a higher error rate for pictures with late-acquired (5.2%) than early-acquired (2.1%) names. Neither picture format nor the interaction of format and frequency trajectory was significant (Fs < 1). This pattern of results remained the same when only spelling errors were considered.

Discussion

Experiment 1 found two reliable main effects with no interaction. The times to initiate written names were faster for colorized than black-and-white pictures. This shows that the benefit of color previously reported for spoken naming by Rossion and Pourtois (2004), and by Weekes, Shu, Hao, Liu, and Tan (2007) in Chinese also extends to written naming. Written naming latencies were also faster for objects with high-to-low frequency trajectory (or early-acquired) names than for those with low-to-high frequency trajectory (or late-acquired) names; this replicates the results of Bonin et al. (2004) and Bonin et al. (2006). However, these two effects were entirely additive. This suggests that information flows serially between the object recognition level and the orthographic L-level in written word production.

Our choice of the experimental manipulation of color to index object recognition may be criticized on the grounds that color may not be unambiguously assigned to this level of processing. Recently, Bramão, Inácio, Faísca, Reis, and Petersson (2011) argued that color facilitates the identification of objects at the semantic level for color-diagnostic objects, whereas the facilitatory effect of color stems from the structural level for noncolor-diagnostic objects. The color diagnostic norms provided by Rossion and Pour-

Table 1
Mean Written Naming Latencies in ms (NT), Their Standard Deviations (SDs), and Percentage Error Rates (%Er) in Each Condition of Experiment 1 as a Function of Picture Format and Frequency Trajectory

	Picture format					
	Black-and-white			Colorized		
Frequency trajectory	NT	*SD*	%Er	NT	*SD*	%Er
High-to-low	1,042	114	2.2	926	106	2.0
Low-to-high	1,061	114	5.3	950	123	5.1

tois's (2004) study were used to check our stimuli. The mean color diagnostic scores (on a 5-point scale) were similar for the high-to-low frequency (3.32) and low-to-high frequency items (3.05). Thus, even if Bramão et al.'s claim concerning the locus of color information in object naming is accepted, the effect of color information in our study cannot be attributable solely to the semantic system. It may further be argued that frequency trajectory is not a genuine (or pure) index of access to word-form information, and some studies have indeed found that rated measures of age-of-acquisition (which are related, but not identical, to frequency trajectory) can affect object identification times (e.g., Dent, Catling, & Johnston, 2007). We therefore used two different variables to index the object recognition level and the orthographic L-level in Experiment 2 to pursue our investigation of information flow in written word production.

Experiment 2: Visibility and Objective Word Frequency

In Experiment 2, we used only black-and-white drawings of objects and presented these clearly (i.e., in normal viewing conditions) or in one of two low-visibility conditions, either by rendering the pictures blurry or by adding visual noise. We reasoned that the low-visibility conditions should slow down perceptual identification, as found by Meyer, Sleiderink, and Levelt (1998) in their study of the spoken naming of line drawings with partly deleted contours. The reduction of the visibility of the objects unambiguously taxes the early stages of perceptual processing necessary for object recognition in naming. We chose objective word frequency as a variable to index the L-level, as most researchers attribute the primary effects of word frequency in spoken naming to this level (e.g., Jescheniak & Levelt, 1994), although there are some dissenting views (e.g., Dell, 1990; Navarrete, Basagni, Alario, & Costa, 2006); we return to this issue in the General Discussion. Experiment 2 therefore represents an additional, and potentially stronger, test of whether information flows in a serial-discrete manner (which predicts that the two variables would have additive effects) or in a cascaded manner (which predicts that the effects of the two variables would interact, with the expectation that there would be a larger frequency effect on written latencies under low-visibility than normal viewing).

Method

Participants. Sixty psychology students (mean age = 18 years) from the University of Bourgogne (Dijon, France) took part.

Stimuli. Thirty-six black-and-white drawings were selected from Bonin, Peereman, Malardier, Méot, and Chalard (2003). Half of the objects had names that were of high word frequency, in both counts of adult and child written frequency, and half had names of low word frequency. The adult frequency counts were taken from Lexique (New, Pallier, Brysbaert, & Ferrand, 2004), and the means of the two conditions were 1.87 and 0.86 (log transformed). The child frequency counts were extracted from Manulex (Lété, Sprenger-Charolles, & Colé, 2004), and the means of the two conditions were 2.07 and 0.92 (log transformed). The high- and low-frequency pictures did not differ reliably on name agreement (73% vs. 72%), image agreement (3.43 vs. 3.76), conceptual familiarity (3.54 vs. 2.90), visual complexity (2.66 vs. 2.71), imageability (4.30 vs. 3.96), number of letters (5.17 vs. 5.06), or (log) bigram frequency (3.67 vs. 3.45). With this set of control variables taken into account, the age of acquisition (AoA) of the picture names in the two conditions could not be perfectly matched, and the high-frequency words were acquired somewhat earlier (M = 5.13 years old) than the low-frequency names (M = 7.10 years old). This is not critical to the issues addressed in Experiments 2 and 3, but we return to it in the Discussion of Experiment 3. The names of the pictures used in Experiment 2 are presented in Appendix B.

Procedure. Participants were randomly allocated to one of the three conditions of picture presentation (clear/normal, blurry, or noisy), and there were 20 participants in each visibility condition. In the familiarization stage, the pictures were presented in the same format as in the experimental stage, along with their clearly printed names. The noisy and blurry pictures were created using Adobe PhotoShop CS2. The noisy pictures were created by the application of a monochromatic noise filter, with a density of 75%, and the blurry pictures were created using a Gaussian blur filter with 8-pixels radius. The identical computer, software, and graphic tablet, and experimental procedure used in Experiment 1 were also adopted here.

Results

Employing the same criteria as applied to the data in Experiment 1, 13.65% of the latencies were discarded. Analyses of variance were performed on written latencies and on errors with the between-participants factor of visibility condition (normal, blurry, noise) and the within-participant factor of word frequency (high-frequency vs. low-frequency names). Mean latencies in each condition, together with the associated standard deviations and error rates, are presented in Table 2.

The main effect of visibility was significant, $F_1(2, 54) = 3.39$, $MSE = 57{,}532.12$, $p < .05$; $F_2(2, 102) = 18.04$, $MSE = 13{,}537.69$, $p < .001$. Written naming latencies were substantially slower when the pictures were presented in either a blurry (M = 1,260 ms) or a noisy fashion (M = 1,194 ms) than when presented under normal viewing condition (M = 1,105 ms). The clear condition differed significantly both from the blurry, $t_1(36) = 3.1$, $p < .001$; $t_2(70) = 6.2$, $p < .001$, and the noisy conditions, $t_1(37) = 1.7$, $p < .05$; $t_2(70) = 3.5$, $p < .001$. These latter two conditions also differed from each other, but this difference was significant only in the by-item analysis, $t_1(35) = 1.1$, $p > .05$; $t_2(70) = 2.64$, $p < .01$. The main effect of frequency was signif-

Table 2
Mean Written Naming Latencies in ms (NT), Their Standard Deviations (SDs), and Percentage Error Rates (%Er) in Each Condition of Experiment 2 as a Function of Visual Presentation Condition and Word Frequency

Visual presentation	High-frequency			Low-frequency		
	NT	*SD*	%Er	NT	*SD*	%Er
Normal	1,068	140	5.0	1,141	147	5.8
Blurry	1,213	181	9.3	1,306	160	11.0
Noisy	1,162	179	5.3	1,226	203	7.9

icant, $F_1(1, 54) = 76.46$, $MSE = 1{,}943.97$, $p < .001$; $F_2(1, 102) = 9.63$, $MSE = 13{,}537.69$, $p < .005$, with latencies being faster (on average by 76 ms) for objects with high-frequency than for low-frequency names. However, the interaction between the two factors was absent (Fs < 1). (Furthermore, when only the clear and blurry conditions were included in the analysis, the interaction between frequency and visibility was also absent, Fs < 1.)

The only effect on error rates was the main effect of presentation condition, $F_1(2, 54) = 4.76$, $MSE = 1.568$, $p < .05$; $F_2(2, 102) = 2.06$. There were more errors in the blurry (10.2%) than in the clear (5.4%) condition, $t_1(36) = 3.1$, $p < .005$; $t_2(70) = 1.86$, $p < .05$, and more in the blurry than in the noisy (6.6%) condition, $t_1(34) = 1.7$, $p < .05$; $t_2(70) = 1.36$, $p > .05$, but the noisy and clear conditions did not differ, $t_1(36) = 1$, $p > .05$; $t_2 < 1$. Thus, as was also found for latencies, the blurry condition was more detrimental to the object recognition process than the noisy condition. The main effect of word frequency did not reach significance, $F_1(1, 54) = 2.07$; $F_2(1, 102) = 1.10$, and the interaction between the two factors was absent (Fs < 1).

Discussion

Pictures that were rendered difficult to identify visually, perhaps not surprisingly, took longer to name than pictures that were presented under conditions of normal visibility, and pictures with high-frequency names were written faster than those with low-frequency names. Importantly, these two reliable (and reasonably substantial) effects were entirely additive; this suggests that information flows from the object recognition to the L-level in a serial-discrete manner. For spoken word naming, Meyer et al. (1998) found that pairs of objects that were presented with partially deleted contours took longer to be named (and were looked at longer) than clearly presented drawings and that this effect was also additive with that of word frequency. However, Meyer et al. found that the effect of word frequency was absent when participants had to categorize the objects rather than name them. They suggested that word frequency affects the process of lexical retrieval necessary for naming.

The results of Experiments 1 and 2 could be taken as support for either a serial-discrete or a limited-cascading account of written naming. Our experimental manipulations of mode of visual presentation, which were designed to have their primary effect on the ease of object recognition, did not interact with variables assumed to index processing ease at the L-level. In terms of the framework illustrated in Figure 1, the object recognition level and the orthographic L-level are nonadjacent, as the semantic level intervenes between the two. If variables that have their primary impact on processing levels that are more adjacent in the overall naming process can be shown to have interactive effects, then this would favor the limited-cascading account of written naming. The aim of our next two experiments was to arbitrate between the serial-discrete and limited-cascading account of written naming.

Experiment 3: Contextual Constraint and Objective Word Frequency

In Experiment 3, we followed the same rationale used by Griffin and Bock (1998) in their study of spoken word production and examined the effects of contextual constraint and word frequency in written picture naming. Whereas Griffin and Bock used high-constraint (e.g., "The astronauts landed on the __"), medium-constraint (e.g., "The satellite orbited the __"), and low-constraint sentences (e.g., "The computer will display a __"), we used only high- and low-constraint sentences. (Note that Griffin & Bock's "low-constraint" sentences were very close to providing *no* constraint, other than that the picture's name would be a noun.) As discussed earlier, word frequency is assumed to index L-level processing (either as the retrieval of word-forms or word-form encoding or execution), while contextual constraint is assumed to index the selection of word-forms (i.e., at the semantic level or how semantics activate word-forms). Cascading accounts of written word production must predict that the effects of contextual constraint and word frequency interact, whereas a strictly serial-discrete account must predict that their effects are additive. A similar debate concerning the interaction between semantic factors and word frequency has occurred in visual word recognition (e.g., Lupker & Pexman, 2010; Stone & Van Orden, 1992; Yap, Tse, & Balota, 2009).

Method

Participants. Thirty-six psychology undergraduates (mean age = 18 years) from Blaise Pascal University (Clermont-Ferrand, France) participated in the experiment. None had acted as participants in either of the previous experiments reported.

Stimuli. The same set of pictures as used in Experiment 2 was used here. For each picture, we created two different lead-in sentences, each with the last word missing: a high-constraining sentence and a low-constraining one. As in the Griffin and Bock (1998) study, the low-constraining sentences were semantically "empty," such as "On the computer screen, she saw a small picture of a __" or "Soon you will see a __," which do not enable any reliable predictions concerning the following, target word. The high-constraining sentences were constructed such that the great majority of an independent group of 25 adults, who did not participate in the naming experiment, provided the intended target name (e.g., "The astronauts landed on the __" [MOON]). The mean degree of predictability of the sentences in the high-constraining condition was similarly high for both the high- (.96) and low-frequency pictures (.85), and these values did not differ reliably ($t < 1$).

Procedure. The same basic procedure (and apparatus) used in Experiments 1 and 2 was also adopted here. There was first a familiarization phase and then the experiment proper. Each experimental trial began with a fixation point (+) displayed in the middle of the screen for 500 ms. Then the lead-in sentence was presented word-by-word at a fixed viewing time of 300 ms per word. Then the stimulus picture was presented until the participant's response, which was to write down the name of the picture on the graphic tablet. Both the high- and low-frequency items were divided into two sets, where one set was presented in the high-constraint and one set in the low-constraint condition for half of the participants, and the assignment of items to condition was reversed for the other half of the participants.

Results

The same criteria used in the previous experiments resulted in the exclusion of 8.5% of the data. Analyses of variance were performed on written latencies and on errors with contextual constraint (high vs. low) and word frequency (high-frequency vs. low-frequency names) as factors. Mean latencies in each condition, together with the associated standard deviations and error rates, are presented in Table 3.

Latencies to write object names were faster (on average by 152 ms) when the pictures were preceded by a high- compared with a low-contextual constraint, $F_1(1, 35) = 115.48$, $MSE = 66{,}2165$, $p < .001$; $F_2(1, 33) = 80.11$, $MSE = 4{,}288.46$, $p < .001$. The main effect of word frequency was significant in the analysis by participants, $F_1(1, 35) = 4.75$, $MSE = 4{,}678.38$, $p < .05$, but just failed to reach significance in the analysis by items analyses, $F_2(1, 33) = 3.18$, $MSE = 3{,}083.19$, $p = .09$. However, the important result was that the interaction between the two factors was significant, $F_1(1, 35) = 12.86$, $MSE = 2{,}600.64$, $p < .001$; $F_2(1, 33) = 4.71$, $MSE = 4{,}288.5$, $p < .05$. Pair-wise comparisons revealed that written latencies were significantly faster (by 48 ms) when producing high- compared with low-frequency names in the low-constraint condition, $t_1(35) = 4.47$, $p < .001$; $t_2(34) = 2.5$, $p < .01$, but there was no reliable effect of word frequency (and, indeed, with a trend, of –9 ms, in the direction opposite to what might be expected) in the high-constraint condition (ts < 1).

The only effect in the analysis of error rates was the main effect of word frequency, $F_1(1, 35) = 42.96$, $MSE = .008$, $p < .001$; $F_2(1, 33) = 11.44$, $MSE = .015$, $p < .001$. Neither the main effect of contextual constraint (Fs < 1), nor the interaction between the two factors, $F_1(1, 35) = 2.40$, $F_2 < 1$, was significant.

Discussion

The results of Experiment 3 were clear-cut: The effects of contextual constraint and word frequency interacted, such that a high contextual constrain effectively eliminated the effect of word frequency on written naming latencies. It is important to note that exactly the same target objects were used in Experiments 2 and 3; all that differed was the experimental condition under which these were presented. In Experiment 2, the effect of word frequency was additive with our experimental manipulation of visibility, whereas in Experiment 3 frequency interacted with our manipulation of contextual constraint. The observed interaction between word frequency and contextual constraint mirrors the pattern found by Griffin and Bock (1998) for spoken naming latencies, showing that their results generalize to written word production. The theoretical importance of the results is that information flows in cascade within the system underlying written naming.

Table 3
Mean Written Naming Latencies in ms (NT), Their Standard Deviations (SDs), and Percentage Error Rates (%Er) in Each Condition of Experiment 3 as a Function of Contextual Constraint and Word Frequency

Contextual constraint	High-frequency			Low-frequency		
	NT	*SD*	%Er	NT	*SD*	%Er
High-constraint	865	158	2.1	856	178	11.4
Low-constraint	989	148	3.7	1,037	142	14.0

As mentioned earlier (in the stimuli section of Experiment 2), the high-frequency names were acquired somewhat earlier than the low-frequency names, which may be seen as a potential weakness. In general, there is a modest, but reliable, correlation between rated AoA and word frequency (–.367 in the French study of Alario & Ferrand, 1999), and so it was not particularly surprising that the effect of word frequency was washed out when AoA scores were introduced as covariates in the analyses from Experiments 2 and 3. However, this does not undermine our rationale, since AoA effects have generally been interpreted as being located at the word-form level and not at the level of object recognition or comprehension (Johnston & Barry, 2006). Nevertheless, to ensure that word frequency is indeed the key factor that interacts with contextual constraint, in Experiment 4 the high- and low-frequency words were carefully matched for AoA in addition to the other important factors.

A more important concern regarding Experiment 3 relates to the type of constraining sentences used. We did not include a condition in which the pictures followed a *potentially* high-constraining sentence but were, in fact, unexpected or even anomalous (e.g., "The astronauts landed on the __" DOG). Given that the participants already knew the possible targets from the familiarization phase, they may have (at least on some trials) anticipated which picture would follow a high-constraining sentence; for example, having seen the sentence "The astronauts landed on the __," presented at a rate of 300 ms per word, participants may have strongly expected to produce the word "moon" before the picture appeared. If this were the case, then it would seriously undermine our theoretical conclusions concerning cascaded processing in written naming. In order to eliminate this theoretically uninteresting alternative account, we therefore incorporated in Experiment 4 a condition with *unrelated* sentences (e.g., "The astronauts landed on the __" DOG) in an attempt to eliminate strategic anticipations, and we also used a quicker presentation rate of the words comprising the sentences.

Experiment 4: Contextual Constraint and Word Frequency (With Rated AoA Controlled)

This experiment tested the same hypothesis as in Experiment 3 but included two important improvements. First, in order to minimize the likelihood of strategic anticipation of which word to write, the experiment contained an *unrelated* condition where the target pictures were preceded by semantically rich and potentially highly constraining sentences (e.g., "The astronauts landed on the __") but where the target picture would be quite unexpected (e.g., DOG). This condition was included as a control against the possibility that the results of Experiment 3 were due only to strategic expectation, and so the unrelated sentences serve essentially as "fillers," as their presence would reduce the likelihood that participants anticipated the name of the pictures from a few words of the lead-in sentences. Experiment 4 also reduced the word-by-word presentation rate of the sentences to a fixed viewing time of 200 ms per word to avoid participants employing a predictive strategy. If the results of Experiment 4 replicate the crucial interaction found in Experiment 3 (namely, that the frequency effect found in the low-constraining sentence condition is eliminated in the high-constraining condition), then this would eliminate the explanation based upon strategic prediction and so support the account based on cascaded processing in written naming.

Second, we manipulated the word frequency of the picture names while also controlling for rated AoA, in addition to the important variables of name agreement, image agreement, conceptual familiarity, visual complexity, number of letters and bigram frequency. A within-participant design was used so that each picture appeared, in a random order, in each of the three contextual conditions (namely, the high- and low-constraining sentences as in the previous experiment and the unrelated sentences).

Method

Participants. Thirty-six psychology undergraduates (mean age = 18 years) from the University of Bourgogne (Dijon, France) participated in the experiment. None had been involved in either of the previous experiments reported.

Stimuli and procedure. Two items ("piece" and "fille") from the set of pictures used in Experiment 3 were removed and 16 pictures (eight high- and eight low-frequency) were added (see Appendix B). As in Experiment 3, half of the stimuli had names that were of high word frequency, in both counts of adult and child written frequency (taken from the same databases as listed in Experiment 3), and half had names of low word frequency. The means of the two conditions were 1.77 and 0.76 (log transformed) for the adult frequency and 1.88 and 1.01 (log transformed) for the child written frequency. We were careful to choose new stimuli in order to keep the controls described in Experiment 3. Likewise, we were able to control the high- and low-frequency items for name agreement (78.5% vs. 79.1%), image agreement (3.43 vs. 3.78), conceptual familiarity (3.42 vs. 2.90), visual complexity (2.75 vs. 2.83), imageability (4.14 vs. 4.16), number of letters (5.33 vs. 5.38), and (log) bigram frequency (3.70 vs. 3.55). Importantly, we were also able to control for rated AoA across the sets of high and low-frequency names (2.33 vs. 2.59).

For each picture, we created three different lead-in sentences, each with the last word missing. As in Experiment 3, the low-constraining sentences were semantically "empty" (e.g., "Soon you will see a __") and the high-constraining sentences were semantically "full." In order to create these sentences, we asked an independent group of 25 adults, who did not participate in the naming experiment, to fill the gap of each sentence with a word (e.g., [MOON] for the sentence "The astronauts landed on the __."). The mean degree of predictability of the sentences in the high-constraining condition was high and did not differ reliably for the high- (.91) and low-frequency items (.85) ($t < 1$). Unlike Experiment 3, we added an unrelated condition where the sentences were semantically "full" but the picture name was completely unpredictable (e.g., "The astronauts landed on the __" [ROPE]). Stimuli in the unrelated condition were created by reassigning those in the related items.

The procedure was very similar to that in Experiment 3. There was first a familiarization phase and then the experiment proper. However, given the high percentage of errors found in the low-frequency items in Experiment 3, the familiarization phase was more extensive. The participants were tested several times on their learning of the names of the pictures to ensure that they knew perfectly the names before the proper naming experiment.

Each experimental trial began with a fixation point (+) displayed in the middle of the screen for 500 ms. The lead-in sentence was presented word-by-word at a fixed viewing time of 200 ms per word. Then the stimulus picture was presented until the participant's response, which was to write down the name of the picture on the graphic tablet. Both the high- and low-frequency items were divided into three sets. These were counterbalanced within a Latin-square design such that each item was presented once in each of three blocks of trials, in one of the three contextual conditions, and within each block the three contextual conditions appeared equally often. Within each block, the items were presented in a random order.

Results

The same criteria used in the previous experiments resulted in the exclusion of 4.1% of the data. Analyses of variance were performed on written latencies and on errors with contextual constraint (high, low, unrelated) and word frequency (high- vs. low-frequency names) as factors. Mean latencies in each condition, together with the associated standard deviations and error rates, are presented in Table 4.

In the analysis of the written latencies, the effect of contextual constraint was significant, $F_1(2, 70) = 103.1$, $MSE = 1,287$, $p < .001$; $F_2(2, 92) = 81.137$, $MSE = 1,160$, $p < .001$. Pictures preceded by high-constraining sentences were named significantly faster (793 ms) than by low-constraining sentences (854 ms), $t_1(35) = 9.33$, $p < .001$; $t_2(47) = 8.64$, $p < .001$. Unrelated sentences yielded longer written latencies (876 ms) than both the high-constraint, $t_1(35) = 11.26$, $p < .001$; $t_2(47) = 9.08$, $p < .001$, and the low-constraint conditions, $t_1(35) = 5.76$, $p < .01$; $t_2(47) = 3.63$, $p < .01$.

The main effect of word frequency was not significant, $F_1(1, 35) = 3.69$, $MSE = 322.6$, $p > .05$; $F_2 < 1$, but crucially for our purpose, the interaction between contextual constraint and frequency was significant by participants, $F_1(2, 70) = 4.812$, $MSE = 541.8$, $p < .05$; and was almost significant in by-item analysis, $F_2(2, 92) = 1.944$, $MSE = 1,160$, $p = .073$. In the low-constraint condition, high-frequency picture names were written faster (by 17 ms) than low-frequency picture names, $t_1(35) = 3.82$, $p < .001$; $t_2(46) = 1.89$, $p = .033$. However, the frequency effect was not reliable when the pictures were preceded by high-constraining sentences (where, as in Experiment 3, the effect ran in the opposite

Table 4
Mean Written Naming Latencies in ms (NT), Their Standard Deviations (SDs), and Percentage Error Rates (%Er) in Each Condition of Experiment 4 as a Function of Contextual Constraint and Word Frequency

Contextual constraint	High-frequency			Low-frequency		
	NT	*SD*	%Er	NT	*SD*	%Er
High-constraint	797	165	3.1	790	165	2.8
Low-constraint	846	167	4.9	863	164	4.5
Unrelated fillers	874	167	5.0	878	171	3.8

direction by 7 ms), $t_1(35) = 1.25$, $t_2 < 1$, or by unrelated sentences (4 ms; both t_1 and $t_2 < 1$). When the unrelated condition was removed from the analysis, the interaction between contextual constraint and frequency was significant both by participants and by items, $F_1(1, 35) = 10.16$, $MSE = 512.4$, $p < .005$; $F_2(1, 46) = 4.71$, $MSE = 1{,}194.6$, $p < .05$.

The only effect in the analysis of error rates to reach significance was the main effect of contextual constraint, $F_1(2, 70) = 4.94$, $MSE = 0.726$, $p < .05$; $F_2(2, 92) = 3.89$, $MSE = 1.383$, $p < .05$. Participants produced fewer errors when pictures were preceded by high-constraining sentences (3%) than by low-constraining sentences (4.7%), $t_1(37) = 2.72$, $p < .05$; $t_2(47) = 2.65$, $p < .05$. There were no reliable main effect of frequency, and no reliable interaction effect of frequency and contextual constraint (all Fs < 1).

Discussion

In Experiment 4 we addressed two concerns arising from our interpretation of the results of Experiment 3, namely, the confound of word frequency with AoA and, more important, the possibility that the interaction between contextual constraint and frequency reflected a "floor" effect as a result of participants strategically predicting the targets from the high-constraining sentences. Experiment 4 was therefore conducted with two methodological improvements: The high- and low-frequency items were matched for AoA, and an unrelated condition was included that was designed to prevent reliance on any possible anticipatory strategy. With these additional stringencies, the results replicated the critical interaction between contextual constraint and word frequency that supports the cascaded account of written naming.

Given that the mean latencies in the unrelated condition did not match those in the low-constraint condition and that the word frequency effect was weak and not reliable in the unrelated condition, a skeptical reader might wonder whether our manipulation to avoid participants strategically predicting the targets was optimally effective. The fact that naming times were somewhat slower in the unrelated than in the low-constraint condition is not particularly surprising, given that studies in other domains (e.g., the semantic priming of word recognition; Neely, 1977) have found that, relative to a neutral prime, related primes speed responses, whereas unrelated primes can slow responses. The fact that there was no reliable frequency effect in the unrelated condition (even if the trend was in the expected direction) is more puzzling. At present we have no clear explanation for this, although we suspect that the frequency effect was "diluted" as a result of dealing with the highly anomalous situations depicted in the unrelated condition (e.g., "an astronaut landing on a DOG"). The interpretation of the results from the unrelated condition (which was included mainly as a *filler* condition to prevent strategic anticipation) requires care. In the domain of reading, Hand, Miellet, O'Donnell, and Sereno (2010) argued that comparisons between contextually congruous (and predictable) and incongruous (but highly anomalous) conditions are not representative of normal processing, and they recommend comparisons between high and less predictable conditions, which is precisely what we did in the high- versus low-constraint conditions in Experiments 3 and 4. There are also other reasons why we believe that the critical interaction between contextual constraint and word frequency could not solely reflect the operation of a possible anticipatory strategy. First, the number of related trials was reduced in Experiment 4 (33%) compared with Experiment 3 (50%), and there is evidence from other domains (e.g., the semantic priming of visual word recognition; Keefe & Neely, 1990) that the proportion of related trials is inversely related to the magnitude of priming effects that involve conscious expectation. Second, in an additional analysis of the results of Experiment 4 that included the factor of block (i.e., the first, second or third presentation of the targets), the interaction between block, constraint, and frequency was absent ($F < 1$). This is inconsistent with the view that participants actively developed any possible strategic anticipation as the experiment progressed. Finally, there were absolutely *no* instances of anticipatory errors being made in the unrelated condition (of the kind "he was tired, so he went to ___" → "bed," when the picture was actually a CAR).

The magnitude of the frequency effect observed in Experiment 4 was smaller than in Experiment 3, which may be attributed to the fact that rated AoA was controlled (see Bonin, Fayol, & Chalard, 2001). The error rate in Experiment 4 was smaller than in Experiment 3 (especially for the low-frequency items), but this renders our theoretical interpretations based on the main latency data more secure. The fact that the overall naming latencies were faster in Experiment 4 than in Experiment 3 (even in the high-constraint condition) is probably due to the more stringent familiarization process adopted in Experiment 4.

General Discussion

The issue of whether information is transmitted between processing levels serially or in a cascaded manner has been investigated extensively in spoken word production and has been the subject of fierce theoretical debates (e.g., Caramazza, 1997; Levelt et al., 1999). It now appears to be generally accepted—even among hardcore proponents of the serial-discrete view—that there is some cascading within the lexical system in speech production, although there remains debate concerning the extent of this cascade. According to the full-cascading position, the flow of information is not restricted, and so when a concept is activated its corresponding lexical and sublexical representations also become activated. In contrast, the limited-cascading view assumes that there is restriction of information flow at particular places within the language production system (such as where decisions are made concerning word selection). For example, Roelofs (1992, 1997) proposed that information flow is task-dependent or goal-related in spoken word production and that any effects of enhanced activation at the L-level will only be found when the task requires it.

The question of how information flows in written word production has been studied less extensively. In order to test the applicability of models of naming to the written domain, we conducted four experiments whose goal was to test between full- and limited-cascading accounts of written naming. We chose experimental manipulations and variables for their ability to index specific processing levels in written word production and, following the logic of Humphreys et al. (1988) and Griffin and Bock (1998), tested whether their effects were interactive or additive. We reasoned that, if activation flows in a continuous and cascading manner between two particular processing levels, then the effects of the variables should interact. In contrast, if the transmission of information between the levels was serial and discrete, then the effects should be additive. Evidence from the picture–picture task has provided strong support for cascaded accounts of naming, but this paradigm has the danger that it engages the language production system in a manner not representative of its usual operation. We therefore used the simple task of writing the names of individually presented objects to test between serial-discrete and continuous-cascaded accounts of written naming.

Experiment 1 compared written naming latencies to black-and-white and colorized drawings of the same objects. We reasoned that this manipulation of presentation format would index the ease with which pictures would be processed at the object recognition level. The frequency trajectory of the object names was also manipulated on the assumption that this would index the ease with which names would become available at the orthographic L-level. We found that there were strictly additive effects of the two variables. In Experiment 2, we selected different variables to index the same two processing levels. The visual quality of the presented pictures was manipulated on the assumption that this would have its primary impact at the object recognition level and the word frequency of the object names was manipulated on the assumption that this would have its primary impact at the orthographic L-level. In line with the findings of Experiment 1, we also found entirely additive effects of these two variables. The results of both Experiments 1 and 2 therefore suggest that information flows serially from the object recognition level to the orthographic L-level in written naming. However, these results do not demand the conclusion that there is *no* cascading in the entire processing sequence of (A) object recognition → (B) semantics → (C) orthographic L-level. It is possible that there could be cascading from A→B, which, as Figure 1 shows, is common to the tasks of both spoken and written naming, and/or from B→C, even if we found no support for cascading from A→C for written naming. Humphreys et al. (1988) argued that there is cascading from object recognition to the phonological L-level from their finding that structural similarity interacted with frequency in spoken object naming. However, Levelt et al. (1999) criticized the interaction reported by Humphreys et al. on the grounds that their items confounded frequency with conceptual familiarity, a variable that is likely to have its locus at the semantic level, and that the critical interaction between structural similarity and name frequency was not apparent in the data of Snodgrass and Yuditsky (1996).

Experiment 3 investigated the effect of contextual constraint, which we reasoned would index the flow of information from B→C, as well as the word frequency of the object names, which would index activation levels at the orthographic L-level. Using the same stimulus pictures as in Experiment 2, we preceded each picture by a lead-in sentence, presented one word at a time, that was either highly predictive of the object name (e.g., "The astronauts landed on the __ MOON"), or provided only very low-constraint (e.g., "Soon you will see a __ MOON"). We found that the effects of the two variables on written naming times interacted. When pictures were preceded by low-constraint sentences, high-frequency names were produced faster than low-frequency names; this shows that word frequency is a major determinant of the preexisting or resting activation levels of words in the process of orthographic lexical retrieval. However, the effect of frequency was not reliable (and, indeed, showed a trend in the opposite direction) when the pictures were preceded by high-constraint sentences, where the advantage provided by semantic constraint effectively overrides the effect of frequency at word retrieval. Experiment 4 found an identical interaction when an unrelated condition was included to reduce the likelihood of strategic anticipation or prediction of the target object. Therefore, the results of both Experiments 3 and 4 support the view that information flows in a cascaded manner from the semantic level to the orthographic L-level in written naming. We interpret the results from our four experiments as supporting a limited-cascading account of written word production.

The conclusions we draw are entirely dependent on the assumptions made concerning the locus of the effects of the experimental manipulations we chose, as well as our methodological logic. In order to successfully argue that an interaction between two experimental factors supports an account based upon cascading activation flow, it is necessary to also convincingly argue that the two interacting factors do not affect the same stage. Although it is beyond our scope here to undertake an evaluation of additive factors methodology as applied to cascading processing architectures, we must now consider in some detail our assumptions concerning the precise functional location of our manipulated variables.

In Experiment 1, we examined the difference between naming of black-and-white drawings and the same items colorized on the hypothesis that this experimental manipulation would index processing at or around the object recognition level. Although it is not unreasonable to assume that the perceptual analysis of color would have some effect at the perceptual level (either by increasing general processing demands or by providing useful additional information to achieve object recognition), it is not certain that color information has its primary effect only at this level. One likely possibility is that, as color can be an important and indeed highly *diagnostic* feature of certain objects (e.g., yellow for lemon), and as knowledge of sensory properties can be represented at the semantic level, then colorized pictures will have more efficient access to the semantic system (Bramão et al., 2011). Experiment 1 found that written naming latencies were over 100 ms faster to colorized than black-and-white drawings, which shows that color clearly provides beneficial information, but this main effect alone cannot tell us whether it assists object recognition or access to semantics. However, there were only few highly color diagnostic objects among both the high-to-low frequency and low-to-high items in Experiment 1 (which, further, did not differ reliably on degree of color diagnostisity). This suggests that, even if we accept that the locus of color information in object naming is located at the semantic system for highly color-diagnostic objects, the effect of color in our experiment cannot be entirely attributable to the semantic system. Furthermore, given that Experiments 3 and 4 found an interaction between our semantic and lexical variables (indicative of cascaded processing), whereas Experiment 2 found no interaction between our structural and lexical variables, it is likely that the color manipulation in Experiment 1 primarily affected the structural and not the semantic level, otherwise they too should have interacted, but they did not.[1] Whatever the resolution of the debate concerning the ultimate level(s) at which color has an effect, the results of Experiment 1 show that the effect of color does not cascade to the L-level.

[1] We thank an anonymous reviewer for alerting us to this form of argument.

We submit that the low-visibility conditions manipulated in Experiment 2 more obviously affect ease of object recognition. We found that presenting objects in a burry or noisy manner slowed written naming latencies by a considerable extent but did so equally for the production of both high- and low-frequency words. Thus, both the effect of the addition of color (which speeds overall naming times) and the effects of the visual format (which slow naming times) provide additive influence upon the effects of lexical variables: Processing at the object recognition level does not cascade to the L-level. These results suggest that processing prior to the transmission of semantic information to the L-level operates in an entirely serial and discrete fashion within the overall process for naming.

The manipulation in Experiments 3 and 4 of contextual constraint represents what we take as an unambiguous and direct index of how semantic information is passed to the L-level to affect lexical selection (Griffin & Bock, 1998). This is also supported by Beattie and Butterworth's (1979) findings that contextual constraint (but not word frequency) affects hesitation behavior of speakers in spontaneous conversations. The results of Experiments 3 and 4 showed that the effect of high contextual constraint effectively eliminated any advantage for high-frequency words on the speed with which they can be retrieved and written. This supports a cascading account of how semantic information is passed to the orthographic L-level.

Frequency trajectory has not often been investigated in picture naming, but Pérez (2007) has criticized it strongly (see Bonin, Méot, Mermillod, Ferrand, & Barry, 2009). Observed effects of frequency trajectory have been interpreted in terms of age-limited learning, as has been the case with effects found with other measures of AoA. There are now many studies of AoA effects on spoken naming latencies (see Johnston & Barry, 2006), but some studies have found effects of both AoA and frequency (see Bonin et al., 2003). Unfortunately, there is no consensus concerning the locus of AoA effects, which have been proposed to be at the semantic level (e.g., Belke, Brysbaert, Meyer, & Ghyselinck, 2005), the phonological level (e.g., Barry, Morrison, & Ellis, 1997), or in the connections between different types of representations (Ellis & Lambon Ralph, 2000). However, most accounts of AoA effects in naming have attributed them to the ease of lexical retrieval.

The rationale of our Experiments 2–4 was based on the assumption that word frequency primarily affects the L-level; we believe that this view is relatively uncontroversial. However, there remains debate concerning the precise locus of the frequency effect in naming and whether frequency also affects other processing levels (e.g., Knobel, Finkbeiner, & Caramazza, 2008). We can examine where word frequency might exert an influence by reference to the framework presented in Figure 1. First, it is most unlikely that a lexical variable could operate at the *pre*lexical level of object recognition (Bonin et al., 2006). Second, findings from the name–picture verification task suggest that word frequency does not act at the object recognition and/or semantic level. In this task, participants are presented with a name followed by a picture and have to decide whether the two "match" or not. No effects of word frequency have been found in this task (Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965; Stadthagen-Gonzalez, Damian, Pérez, Bowers, & Marín, 2009). For example, Stadthagen-Gonzalez et al. (2009) found that the times to make "match" responses are affected by relevant visual and conceptual factors (image agreement and conceptual familiarity) but are not affected by lexical variables including word frequency. If word frequency was acting at a semantic level, it should have emerged a reliable predictor of name-object verification times since a genuine semantic variable such as conceptual familiarity was indeed a reliable predictor in that task.

In an influential study of word frequency in spoken word production, Jescheniak and Levelt (1994) proposed that word frequency effects are located at the phonological word-form level. (Dell, 1990, proposed that frequency has its locus at the lemma to word-form connection.) Jescheniak and Levelt found a clear effect of word frequency on object naming times that was also robust over many presentations of the same objects. (There was no frequency effect in a delayed cued-production task, which ruled out a purely articulatory locus.) Jescheniak and Levelt reported no such durable effect of frequency on tasks that require access to a word's grammatical gender, which they assume is represented at the lemma level. However, Navarrete et al. (2006) found a reliable frequency effect on the times to make "masculine/feminine" decisions on the names of target pictures (and for all repeated presentations of the objects); this positive result questions Jescheniak and Levelt's conclusion (and/or models that propose separate lemma and word-form levels). Jescheniak and Levelt also reported finding an effect of "inherited" frequency for homophones in a word translation task with bilingual participants; the production of low-frequency homophones (e.g., "nun") was faster than control words matched for specific frequency (e.g., "owl" = *nun*) but did not differ from words matched to the cumulative frequency of both homophone-twins (e.g., "tooth" = *nun* + *none*). They proposed that it is the frequency of the common phonological form (/boi/), summed from both forms of the homophone ("boy" plus "buoy"), that is critical. However, a number of studies have since found that naming times are determined by the specific frequency of the object names and not by the cumulative (or summed) frequency of homophones (e.g., Caramazza, Bi, Costa, & Miozzo, 2004; Cuetos, Bonin, Alameda, & Caramazza, 2010; but see Jescheniak, Meyer, & Levelt, 2003).

Concerning written naming, it is quite reasonable to assume that word frequency also operates at the orthographic L-level. Although some studies of written naming have found an AoA effect but no effect of frequency (e.g., Bonin, Fayol, & Charlard, 2001), others have found effects of both variables (see Bonin et al., 2004). There is no compelling reason to believe that frequency effects are different for spoken and written naming. We found a clear effect of word frequency in Experiment 2 (and in the low-constraint conditions of Experiments 3 and 4). It is important to note that clear word frequency effects were obtained in Experiments 2, 3, and 4, with important variables controlled for, namely, name-agreement, imageability and word length. Importantly, we were also able to control for rated AoA in Experiment 4. Thus, a word frequency effect that is not confounded with AoA can be observed, which has not been the case in some very influential picture naming studies (e.g., Caramazza, Costa, Miozzo, & Bi, 2001; Jescheniak & Levelt, 1994).

If word frequency proved not to be located at the L-level, then we would be forced to reconsider the conclusions we drew from Experiments 2–4. However, we confidently submit that word frequency effects may be interpreted as a genuine signature of the ease of processing at the orthographic word-form level in written naming in much the same way that frequency affects the phonological level in spoken word production (Mädebach, Jescheniak, Oppermann, & Schriefers, 2011).

We have argued that the results of Experiments 3 and 4 support the view that the flow of information from the semantic to the orthographic L-level in written naming is cascaded, just as Griffin and Bock (1998) argued that their results support a cascaded model of spoken naming. However, if it were the case that written word production was always phonologically mediated, then it would be quite unsurprising that we observed the same pattern of results as in similar studies of spoken word production (and that we arrived at similar theoretical conclusions). Therefore, a critical question for our purposes here is whether the production of single words in writing is phonologically mediated or not.

It is true that there are differences between speech and writing as means of language expression. Writing is a skill acquired later in life than speaking (and, of course, people must learn over many years how to be literate), and it is a less frequently practiced activity (even for the most prolific of authors). Furthermore, writing involves arguably more complex coordination of language-specific and motor control processes than speech, it may executed with less confidence and with less concern for fast, fluent production (and, indeed, it is often supported by appeal to external sources such as spell-checkers and dictionaries), and it generally takes longer to produce than speech. It might therefore be believed that written naming must be dependent upon (or even "parasitic" on) prior and efficient phonological processing (Luria, 1970). It is reasonable to think that phonological processing plays a role in spontaneous writing (where the presence of sound-based writing errors is consistent with the notion that writing follows speech) and in informal note taking and text messaging, where phonological-based processing is often used explicitly (e.g., "C U L8R 2NITE").

Spoken naming is exclusively conceptually and phonological driven, as there can be no *sub*lexical processing to support word retrieval (which is in contrast to reading aloud words or writing auditory words to dictation). However, written naming could, in principle, be supported by both lexical and sublexical phonological mediation. Although not shown in Figure 1, there are two possible processing pathways that may play some role in writing, in addition to the main semantic-to-orthographic L-level pathway: (a) lexical phonological mediation (semantics → phonological L-level → orthographic L-level), which has been advanced to account for the observation that some acquired dysgraphic patients in "contextualized" dictation make homophone substitution errors that involve the production of irregular spellings (e.g., "doe, a deer, a female dear; doe" → *DOUGH*; Roeltgen, Gonzalez-Rothi, & Heilman, 1986); and (b) sublexical phonological mediation (semantics → phonological L-level → phoneme level → phoneme-to-grapheme conversion → grapheme level), which has been advanced to account for observed effects of sound-to-spelling regularity on both spelling accuracy in surface dysgraphic patients (e.g., Rapp, Epstein, & Tainturier, 2002) and written latencies in dictation (e.g., Bonin, Peereman, & Fayol, 2001).

Recently, Zhang and Damian (2010) used the picture–word interference paradigm to investigate the activation of phonological codes in written word production. Participants had to write down the name of pictures while ignoring superimposed printed distractor words. When the pictures and words were presented simultaneously, distractor words that were orthographically and phonologically related to the object name (e.g., *dread*-HEAD, *swear*-BEAR) facilitated handwritten naming latencies (by 36 ms) and did so more than when distractors were only orthographically related (e.g., *bead*-HEAD, *year*-BEAR), where the effect was 11 ms. However, when the distractor word was presented 100 ms after the onset of the picture, both related conditions facilitated written naming latencies equally (43 ms and 55 ms). A stronger case for any role of phonological mediation would be provided by the demonstration that a purely phonological related word with no or minimal orthographic similarity (such as *hot*-YACHT, *quay*-PEA) would also facilitate written naming times, but Zhang and Damian did not include such a condition in their study.

We submit that the possible contribution of any phonological-mediation to written word production is unlikely to have markedly affected the pattern of results we found, for two main reasons. First, the contribution of sublexical phoneme-to-grapheme conversion to written naming latencies appears to be only slight. Bonin, Peereman, and Fayol (2001) compared writing times with *inconsistent* words (e.g., CHAISE, CYNE) and *consistent* control words in French. They found no reliable effect of inconsistency on the latencies to write the names of pictures, although a third experiment found that there was a difference but only when the unusual spelling was at a word-initial position; inconsistency at word-final positions had no effect in naming. This stands in contrast to the reliable consistency effect for both word-initial and word-final in the task of writing auditorily presented words to dictation (Bonin, Peereman, & Fayol, 2001). There were no differences between our high- and low-frequency words in terms of either their sublexical or lexical sound-to-spelling consistency,[2] and so the results cannot be contaminated by any possible effect of phonological mediation. Second, there is increasing evidence for the "orthographic autonomy" account of written naming (Rapp, Benzing, & Caramazza, 1997), which states that the retrieval of lexical orthographic representations does not require obligatory access to, or the necessary mediation of, phonology. For instance, some neuropsychological patients show inconsistent lexical responses in their written and spoken naming of the same targets (e.g., a correct written response and a semantic substitution error in speech, or vice versa; or different semantic errors to the same target, as in the spoken response "church" and the written response "piano" to the stimulus *organ*; Miceli & Capasso, 1997; Miceli, Capasso, & Caramazza, 1999). Different responses in written compared with spoken picture naming cannot be explained by the obligatory phonological mediation hypothesis, which predicts that phonology underlies both forms of language production.

In their investigation of how information flows within the lexical system in written naming using the picture–picture paradigm, Roux and Bonin (2012) found facilitatory effects from distractors

[2] The high- and low-frequency words used in Experiment 2–4 did not differ in their sublexical phoneme-to-grapheme consistency, as assessed for their onsets, vowels, and rimes ($ts < 1$) or lexical sound-to-spelling relationships (as only three object names were heterographic homophones).

with phonologically and orthographically related names (e.g., COUTEAU and COURONNE) and whose names shared an initial letter but not the initial sound (e.g., CANARD and CITRON). Importantly, they also found that distractors whose names shared the initial sound but not the initial letter (e.g., SERPENT and CITROUILLE; an English example would be CAKE and KITE) did *not* produce facilitation. (Control tasks ruled out a perceptual and conceptual account of the orthographic facilitation effect found in the naming experiments.) Roux and Bonin's results support full-cascading accounts of written naming, as the recognition of an object leads to the (automatic) activation of the orthographic form of its name. However, a potential drawback of their study is that the picture-picture paradigm is a complex and somewhat unnatural task. To avoid these criticisms, we used the simpler and standard technique of writing the names of individually presented pictures, and importantly, we found that cascading is restricted within the conceptual-lexical written naming system.

In conclusion, our findings provide support for a limited-cascading account of written naming: Information flows in cascade from the semantic to the L-level but does not fully cascade from the object recognition level through to the orthographic L-level.

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Appendix A

Names of Pictures Used in Experiment 1

High-to-low items	Low-to-high items
Âne (donkey)	Ampoule (bulb)
Ballon (balloon)	Bougie (candle)
Canard (duck)	Bouteille (bottle)
Carotte (carrot)	Cadenas (padlock)
Chien (dog)	Canapé (sofa)
Clou (nail)	Canon (cannon)
Clown (clown)	Casquette (cap)
Cochon (pig)	Cerf (deer)
Crocodile (crocodile)	Chemise (shirt)
Escargot (snail)	Cigare (cigar)
Fraise (strawberry)	Cigarette (cigarette)
Gâteau (cake)	Ciseau (scissor)
Hibou (owl)	Cloche (bell)
Lapin (rabbit)	Couronne (crown)
Moto (motobike)	Cravate (tie)
Oiseau (bird)	Cygne (swan)
Panier (basket)	Échelle (ladder)
Parapluie (umbrella)	Fenêtre (window)
Phoque (seal)	Harpe (harp)
Poisson (fish)	Oeil (eye)
Pomme (apple)	Pantalon (trousers)
Renard (fox)	Piano (piano)
Serpent (snake)	Règle (ruler)
Tambour (drum)	Scie (saw)
Tomate (tomato)	Train (train)
Tortue (tortoise)	Valise (suitcase)

(*Appendices continue*)

Appendix B

Names of Pictures Used in Experiments 2, 3, and 4

High-frequency items	Low-frequency items
Cercle (circle)	Banc (bench)
Corde (rope)	Biche (hind)
Croix (cross)	Bombe (bomb)
Doigt (finger)	Brique (brick)
Femme (woman)	Bhope (beer mug)
Feuille (leaf)	Bintre (hanger)
*Fille (girl)	Boffre (chest)
Groupe (band)	Crêpe (pancake)
Jupe (skirt)	Douche (shower)
Lance (lance)	Paume (palm)
Langue (tongue)	*Pièce (piece)
Lettre (letter)	Pion (pawn)
*Lune (moon)	Poulpe (octopus)
Masque (mask)	Puzzle (puzzle)
Nez (nose)	Rat (rat)
Porte (door)	Sphinx (sphinx)
Règle (ruler)	Tank (tank)
Table (table)	*Urne (urn)
**Coupe (cup)	**Clown (clown)
**Branche (branch)	**Bouée (lifebuoy)
**Cadre (frame)	**Capuche (hood)
**Chemise (shirt)	*Chaussure (shoe)
**Prise (plug)	**Pelle (shovel)
**Crâne (skull)	**Crabe (crab)
**Poing (fist)	**Poire (pear)
**Canon (cannon)	**Cerise (cherry)

Note. The items marked with a single asterisk were not used in Experiment 4, and those marked with a double asterisk were used in Experiment 4 only.

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